Jets in 200 GeV p+p and d+Au collisions from the STAR experiment at RHIC

Jan Kapitán

Nuclear Physics Institute ASCR, Czech Republic
(for the STAR Collaboration)

CFRJS

ÚJF

STAR

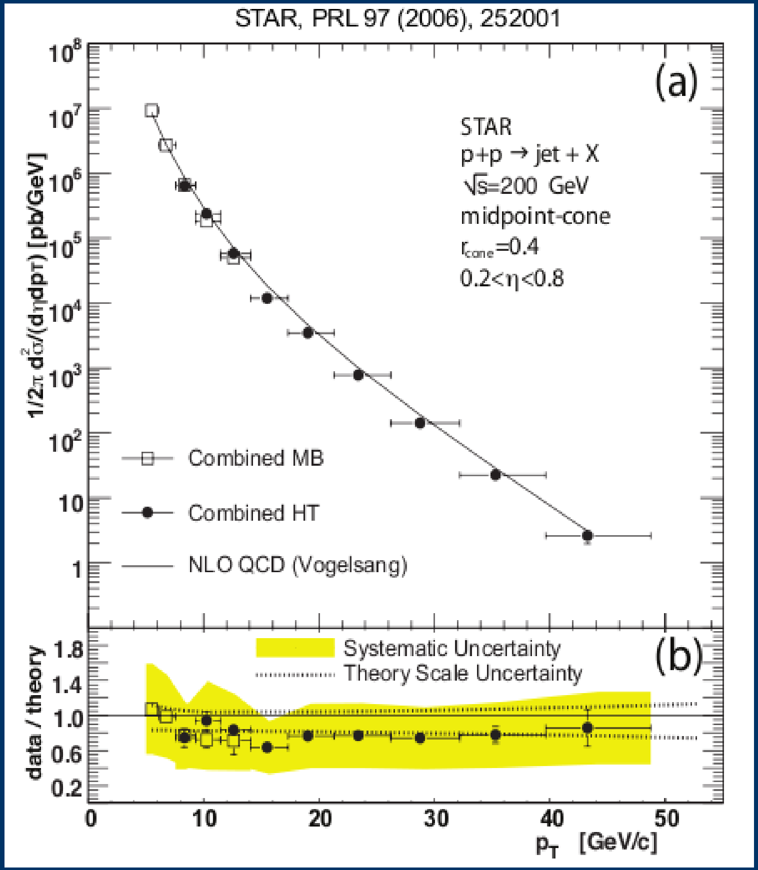
Outline

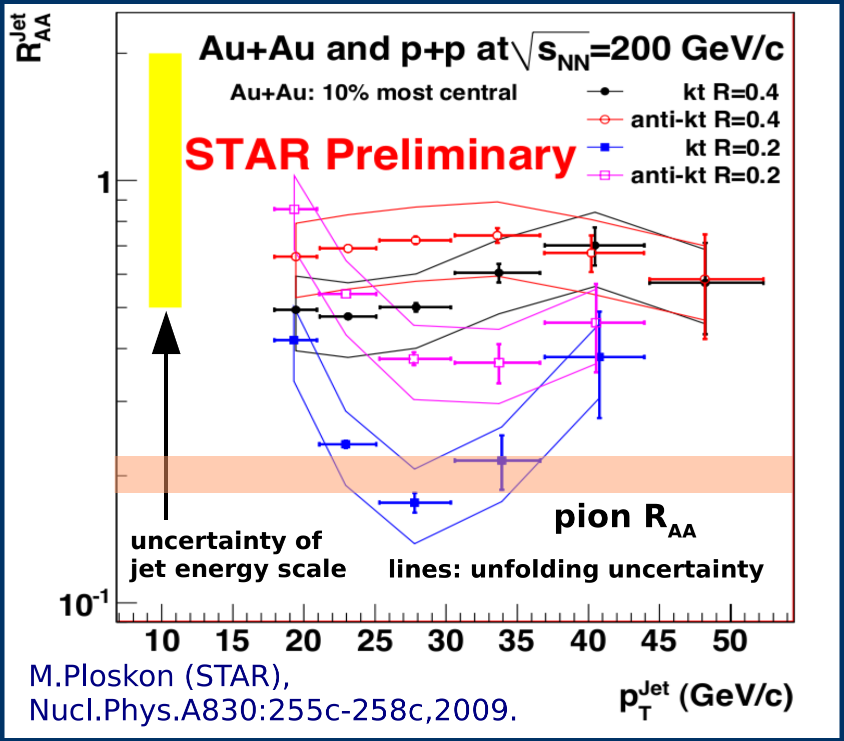
- motivation
- STAR experiment at RHIC
- jet reconstruction technique
- di-jets in p+p and d+Au collisions
- jet p_T spectrum from d+Au collisions

Motivation

jets:

- well calibrated probe (pQCD)
- access to partonic kinematics
- Heavy-Ion collisions: direct study of jet quenching





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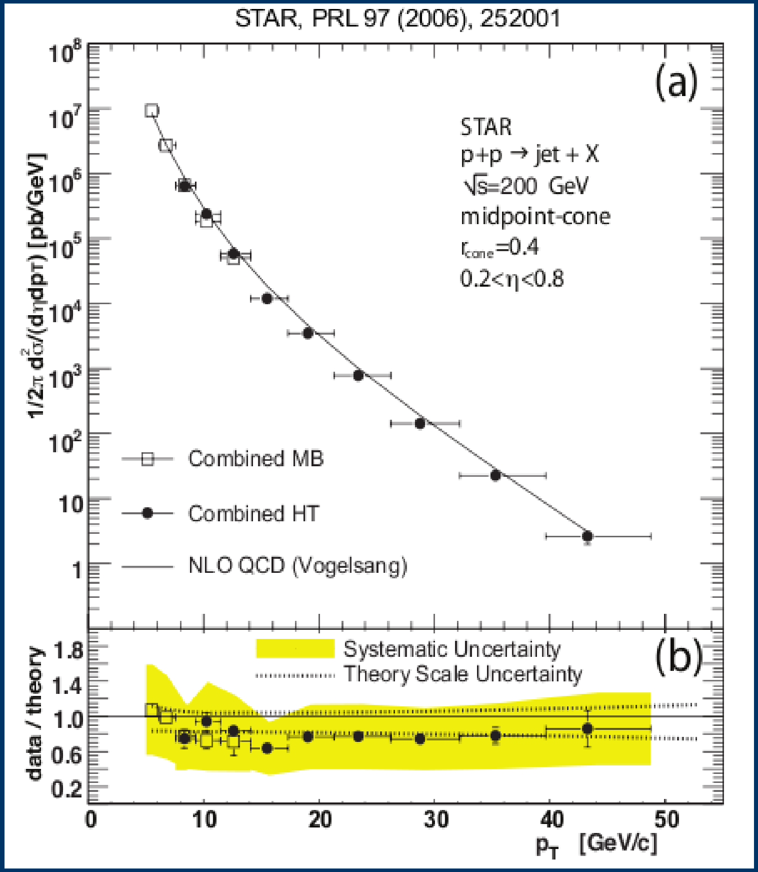
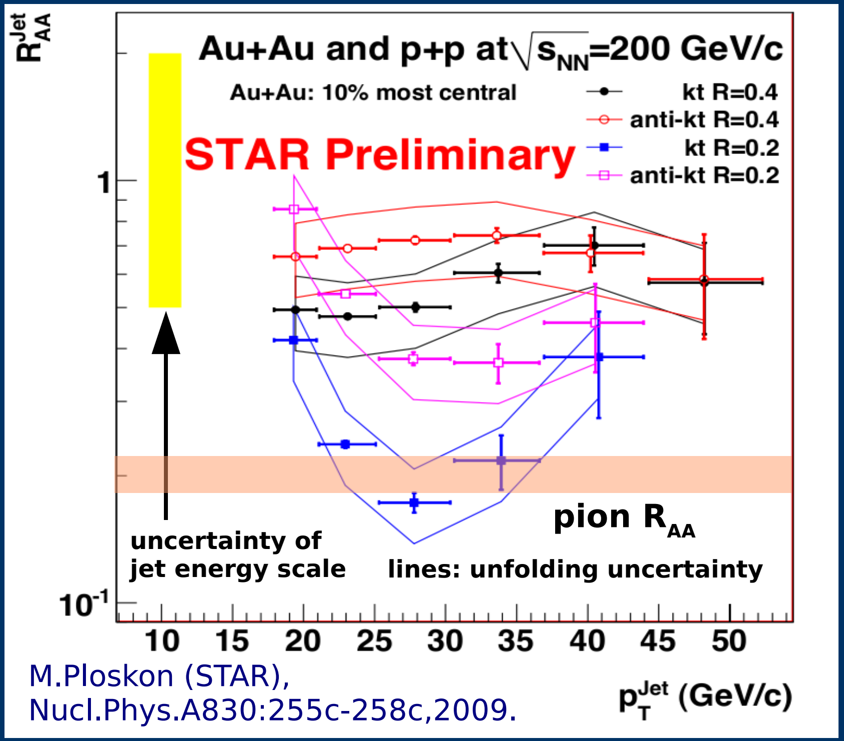
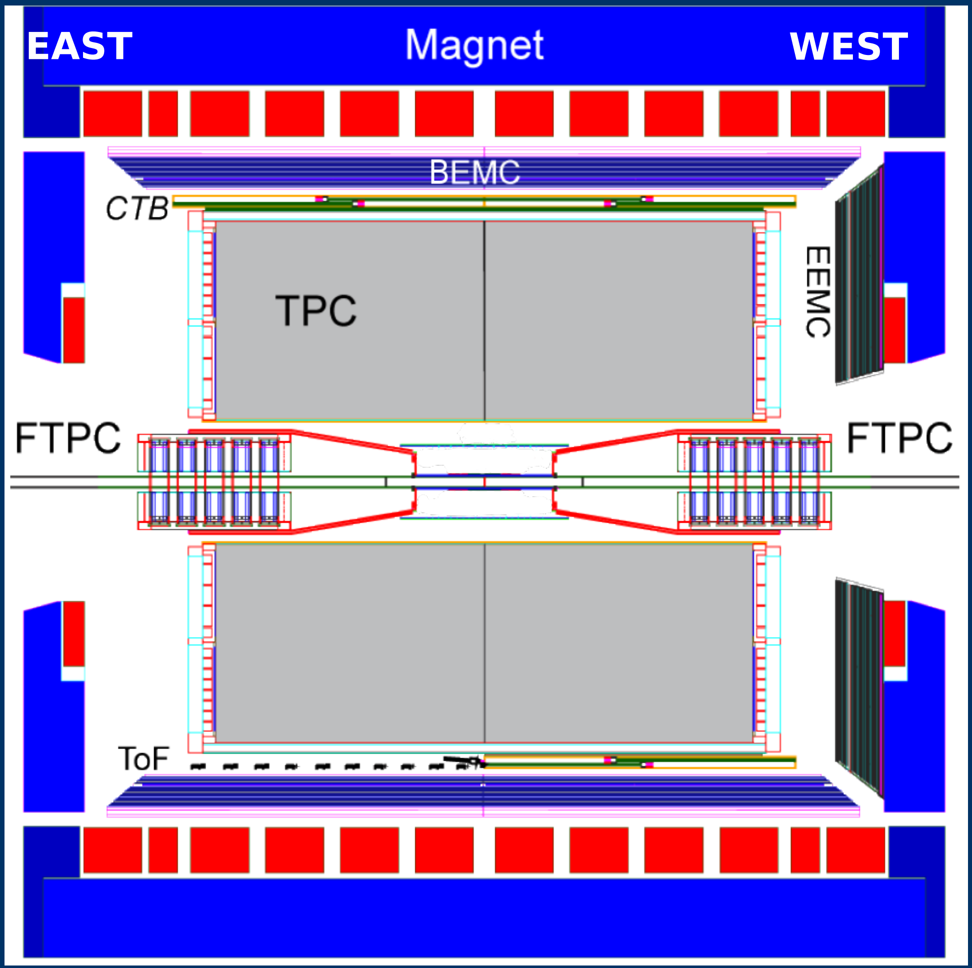




d+Au: estimate initial state effects

- di-jet correlations and jet p_T spectrum
- compare to p+p collisions
- possible effects due to modified PDF and parton rescattering in cold nuclear matter (CNM)

STAR experiment at RHIC



solenoidal magnetic field 0.5 T

detectors used ($|\eta|<1$, Φ: 2π):

- Time Projection Chamber: tracking
- Barrel EM Calorimeter (BEMC):
  - -neutral energy (towers 0.05x0.05)
  - -trigger

“100% hadronic correction”: subtract matched track p_T off tower E_T: avoid double-counting (MIP, electrons, hadronic showers)

d+Au centrality: selected 20% highest multiplicity events using East FTPC

data used in this analysis: 200 GeV p+p & d+Au run 8 (2007/2008)

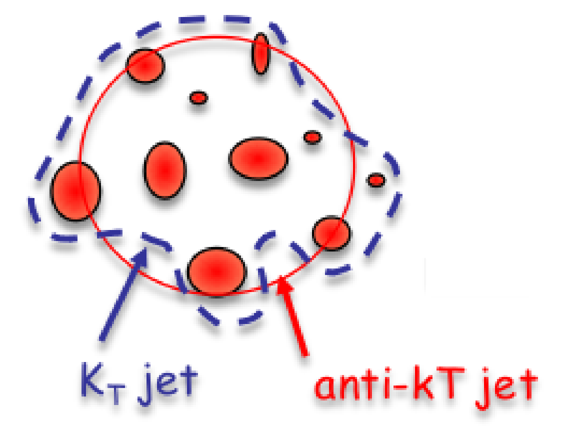
Jet reconstruction

recombination algorithms - FastJet package

Cacciari, Salam and Soyez, JHEP0804 (2008) 005.

- $d_{ij} = \min(p_{Ti}^n, p_{Tj}^n)\,(\Delta\eta^2+\Delta\varphi^2)/R^2$, $d_i = p_{Ti}^n$
- $\min(d_i, d_{ij})$: d_i -> new jet, d_{ij} -> merge i,j

- n=2: kt, n=-2: anti-kt
- R: resolution parameter
- recombination: E scheme with massless particles



kt algorithm:

- starts with low p_T particles
- sensitive to background!

anti-kt algorithm:

Cacciari, Salam and Soyez, JHEP0804 (2008) 063.

- starts with high p_T particles
- resilient w.r.t. soft radiation
- flexible w.r.t. hard radiation
- less sensitive to background!
- ideal algorithm?

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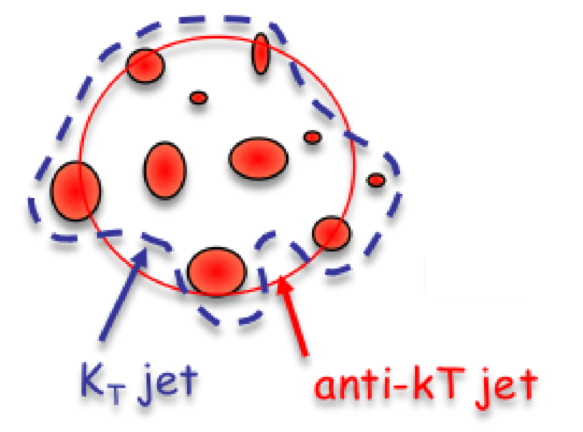

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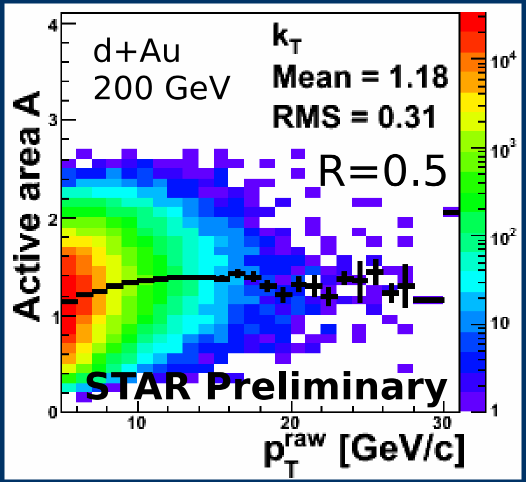
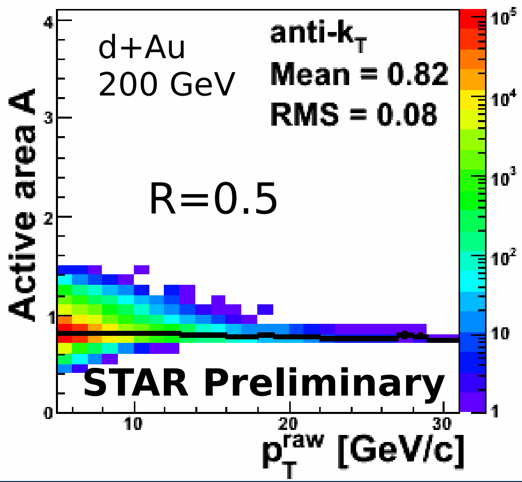
active jet area A: using ghost particles

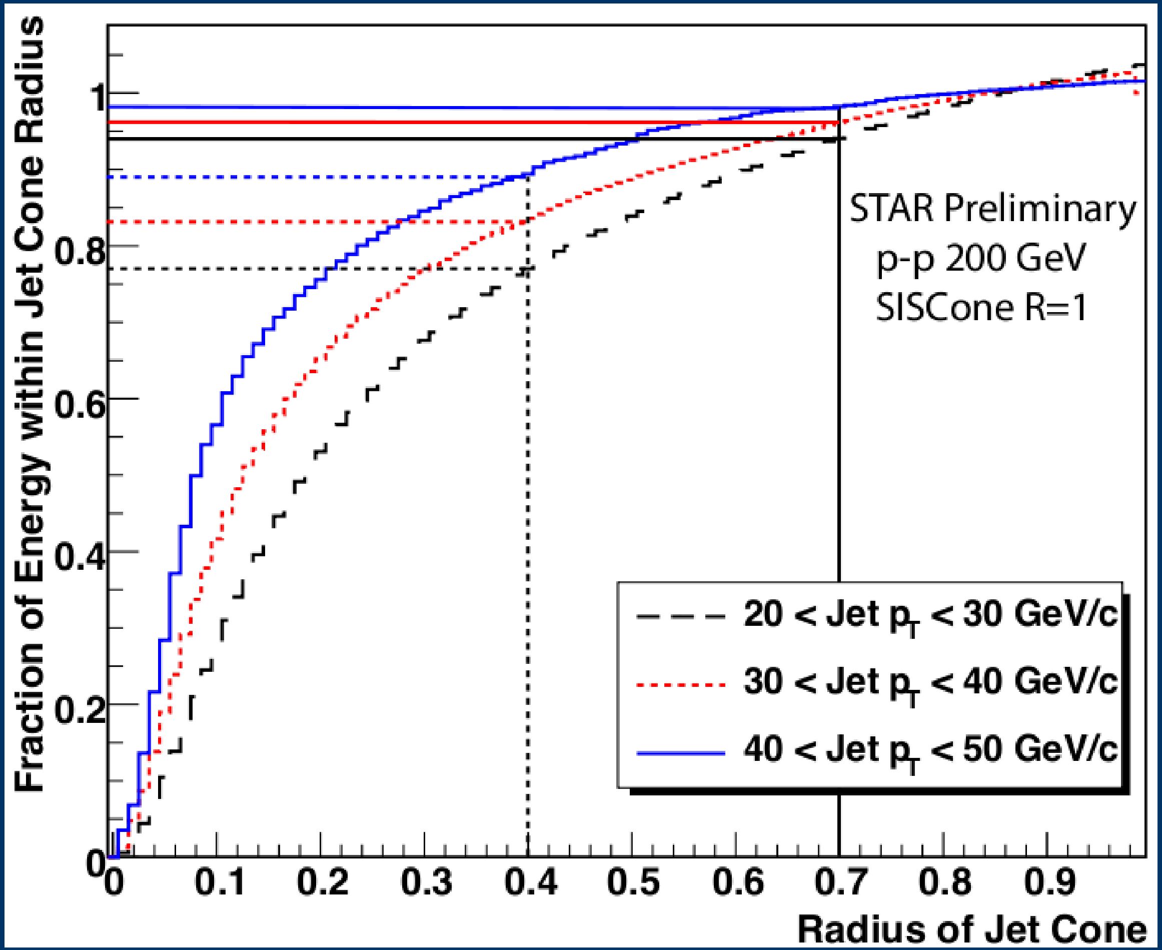




Resolution parameter

choice of R:

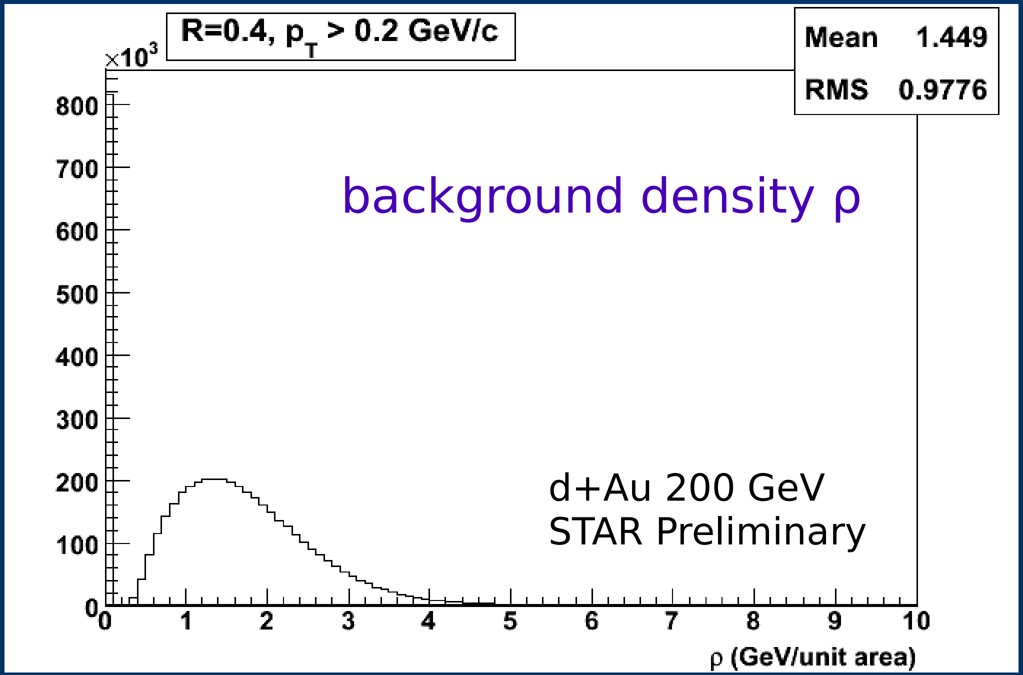
- balance between background and capturing the whole jet
- reasonable values: 0.4 - 0.7



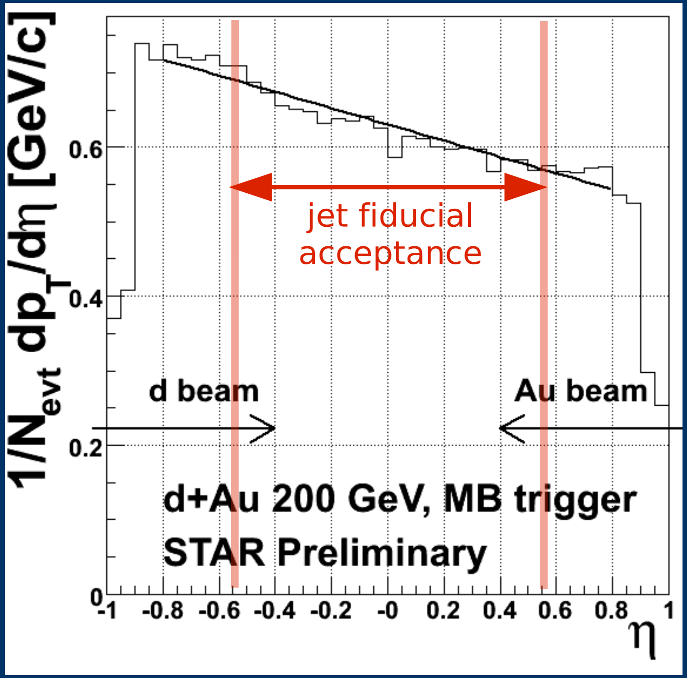
d+Au background

underlying event background

- reduction: lower R (0.4 or 0.5 rather than 0.7), p_T cuts (tracks/towers)
- estimation: background density constructed event-by-event as ρ = median $\{p_T/A\}$ using kt algorithm
- subtraction: $p_{T,jet,true} = p_{T,jet,reconstructed} - \rho * A$



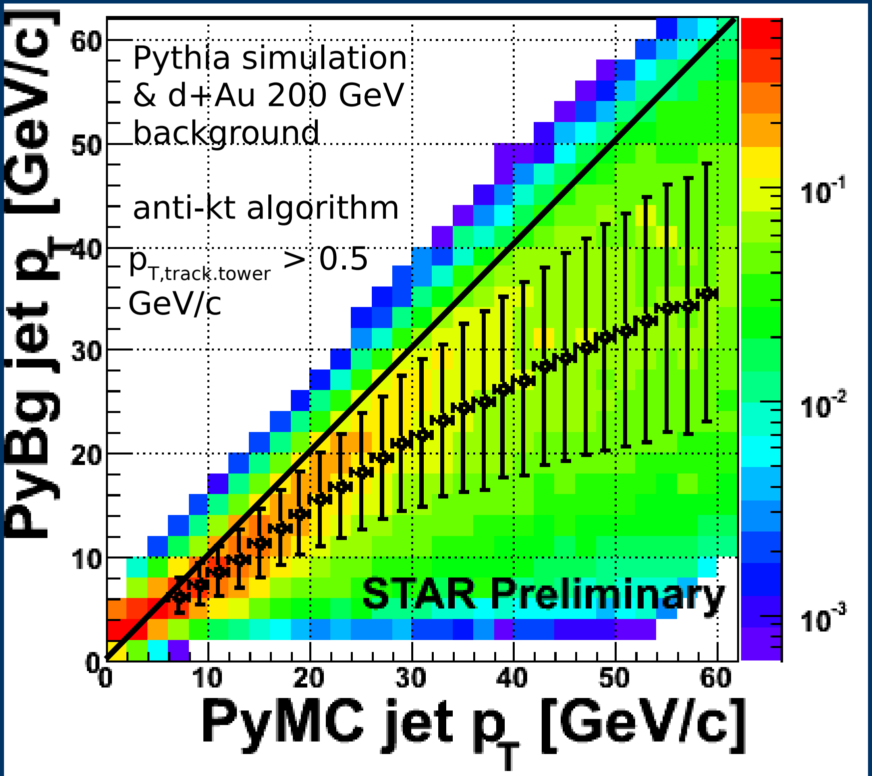
pseudorapidity dependence:



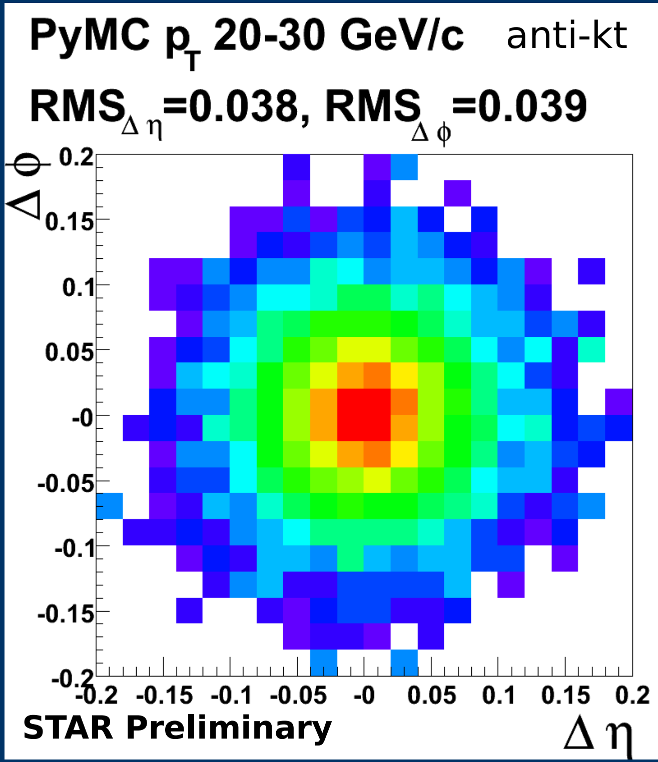
Pythia simulation

- Pythia 6.410, GEANT, STAR simulation & reconstruction software
- PyMC (particle level), PyGe (detector level)
- PyBg: reconstructed Pythia jet event inserted into real d+Au event to estimate residual background effect (looking at matched jets: ΔR<0.2)

jet p_T resolution: ~20%, shift due to K^0_L+n, dead towers, tracking efficiency, track+tower p_T cut



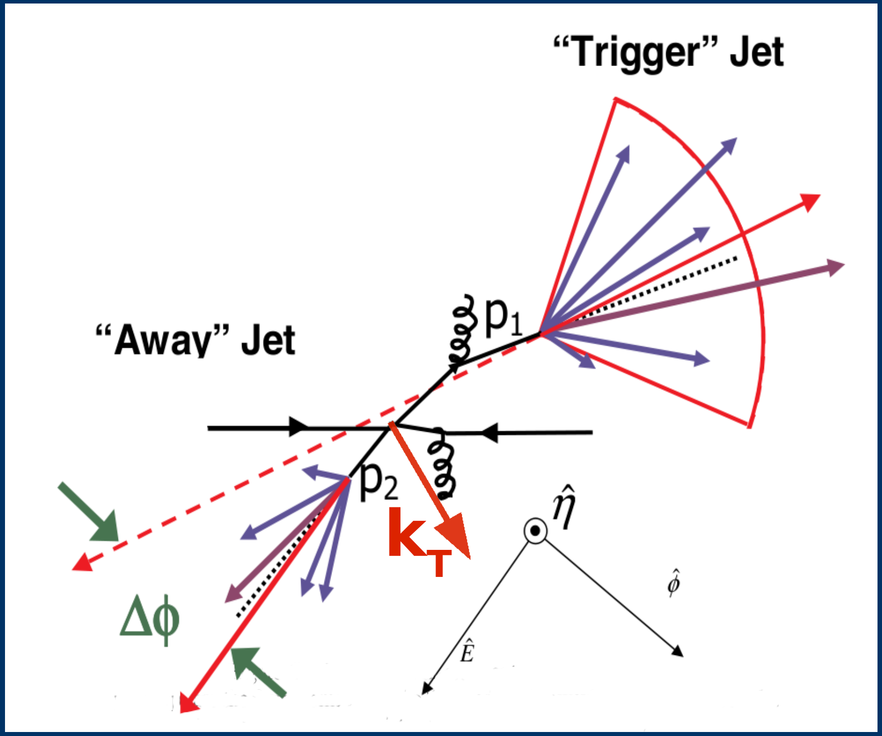
good angular resolution



k_T and di-jets in d+Au collisions

k_T effect (di-jet $\Delta\Phi$ broadening):

- intrinsic k_T + ISR,FSR (incl. CNM effects)
- can be measured through azimuthal component of $\vec{k_T}$



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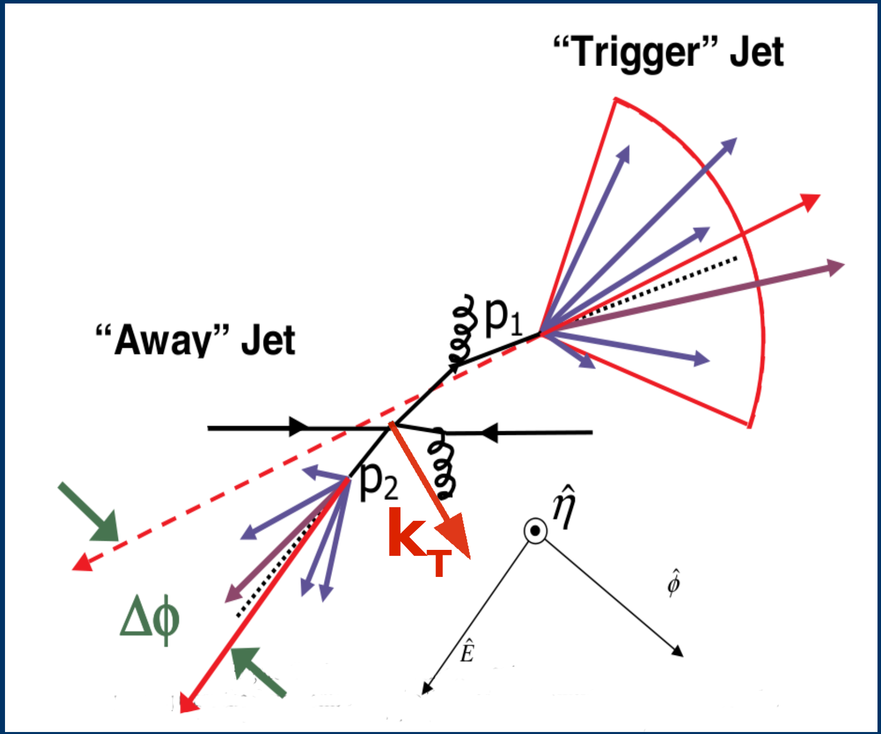
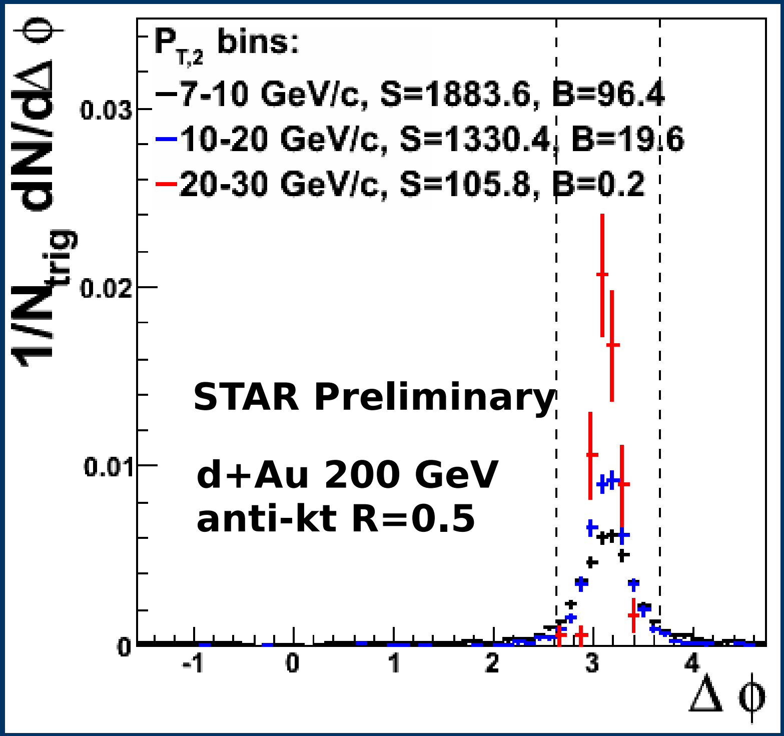
- data used: High Tower (HT) trigger: $E_{T,tower} > 4.3$ GeV
- anti-kt, R=0.5, $p_{T,track/tower} > 0.5$ GeV/c
- 2 highest energy jets in event: $p_{T,1} > p_{T,2}$
- use cut on $p_{T,2}$ to suppress background

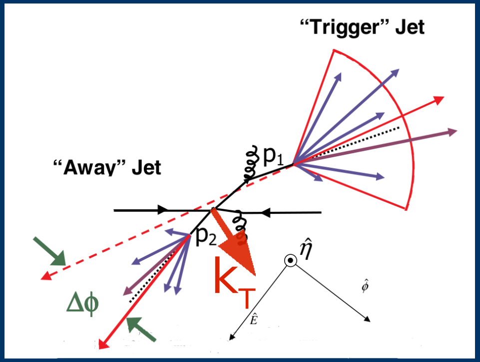




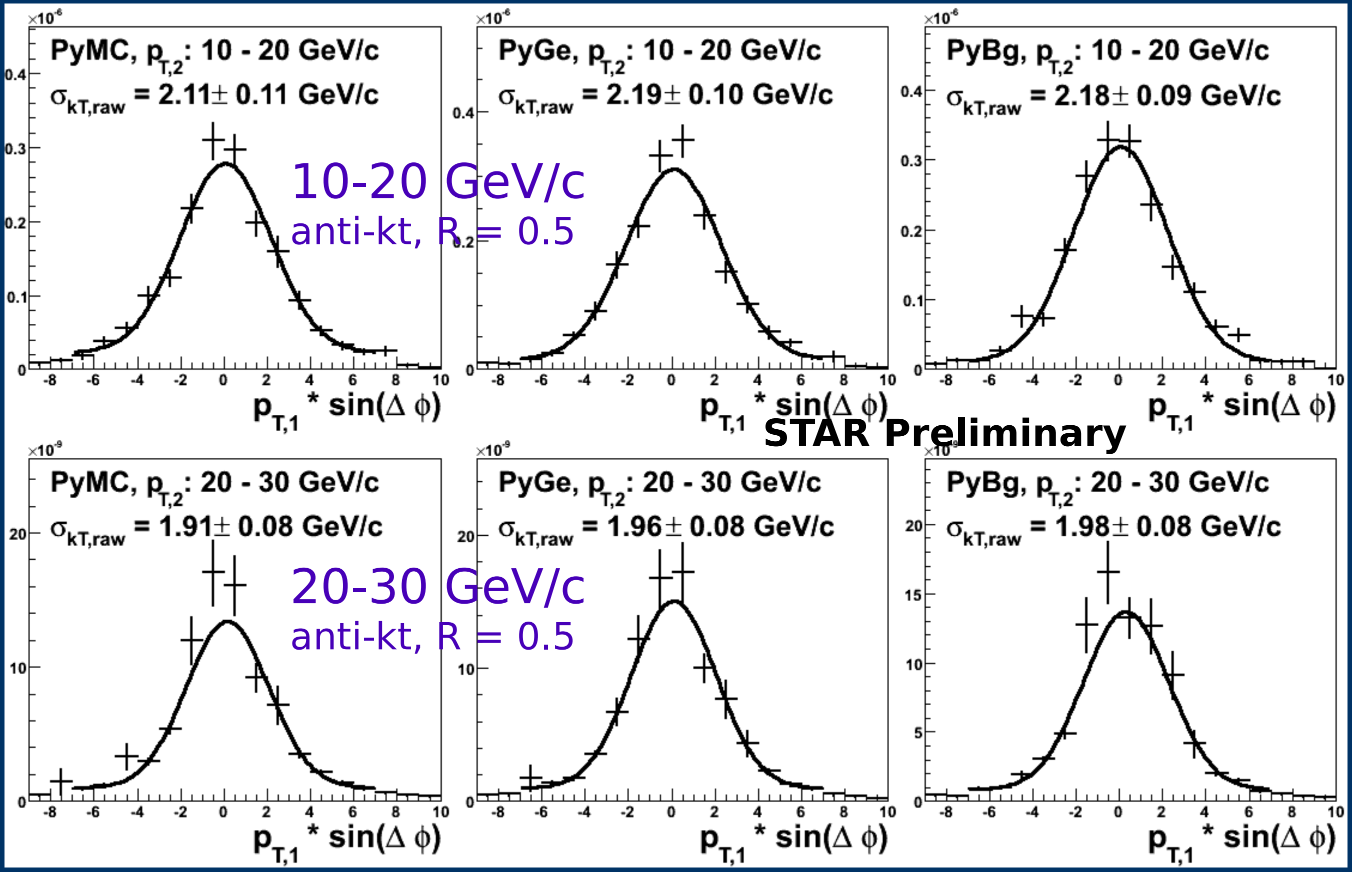
clear back-to-back di-jet peak

Measurement of k_T effect

- measure in d+Au collisions and compare to p+p
- $\mathbf{k_{T,raw} = p_{T,1} * \sin(\Delta\Phi)}$, $|\sin(\Delta\Phi)| < 0.5$, Gaussian fit



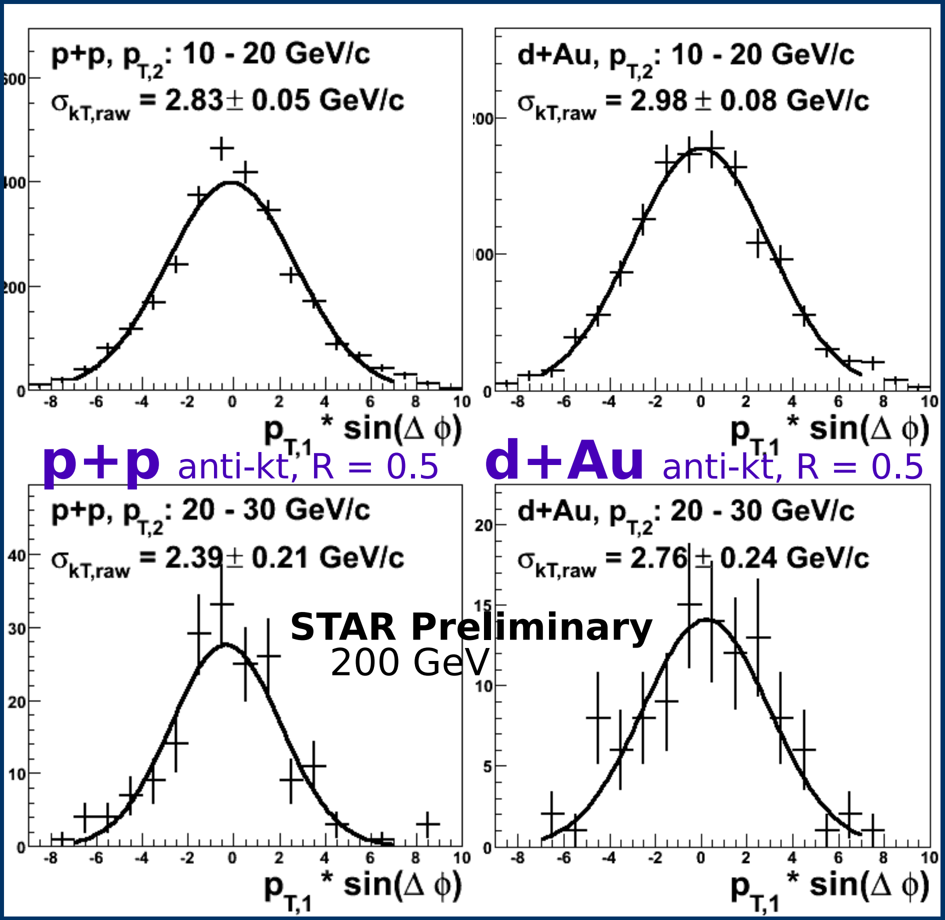
detector effects on k_T measurement:



...resulting detector effects are small, due to interplay of jet p_T and di-jet $\Delta\Phi$ resolutions

Do we see CNM effects on k_T?

- the same analysis technique in p+p and d+Au (run 8, HT trigger)



p_T – averaged values:
$\sigma_{kT,raw}$ (p+p) = 2.8 ± 0.1 GeV/c
$\sigma_{kT,raw}$ (d+Au) = 3.0 ± 0.1 GeV/c
?decrease at high p_T (quark jets?):
higher jet energies to be studied

systematic uncertainties:

- neglecting detector effects
- BEMC calibration
- TPC tracking efficiency
- → in total expected to be less than 10%
- → mostly correlated between p+p and d+Au

no strong effect on jet k_T broadening seen

Towards jet p_T spectrum

200 GeV d+Au data:

- 20% most central collisions from minimum bias trigger data sample
- 10M events after cuts
- p_T reach ~30 GeV/c

additional correction:

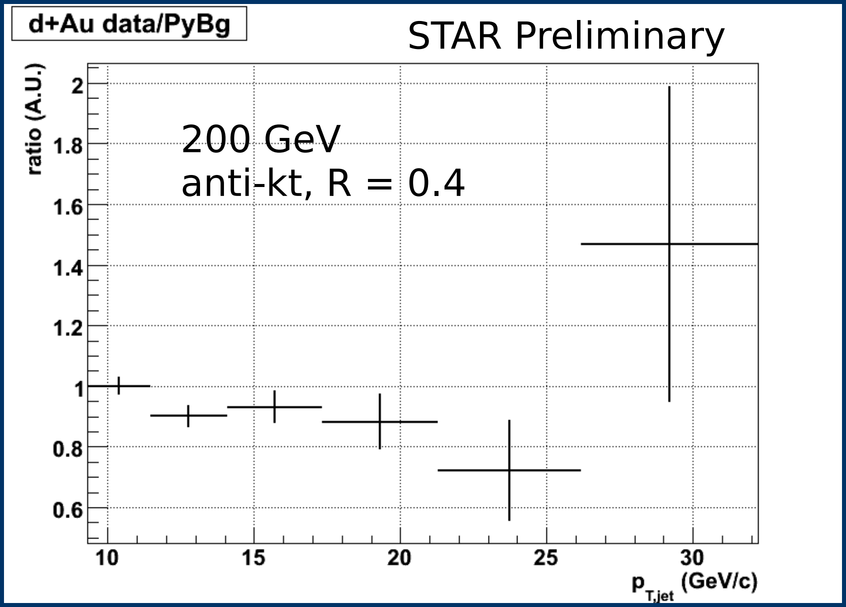
lower tracking efficiency applied to reconstructed tracks before PyBg jet finding: coming from difference between run 8 d+Au realistic detector simulation ("embedding", single particles) and Pythia "ideal" jet simulation

jets:

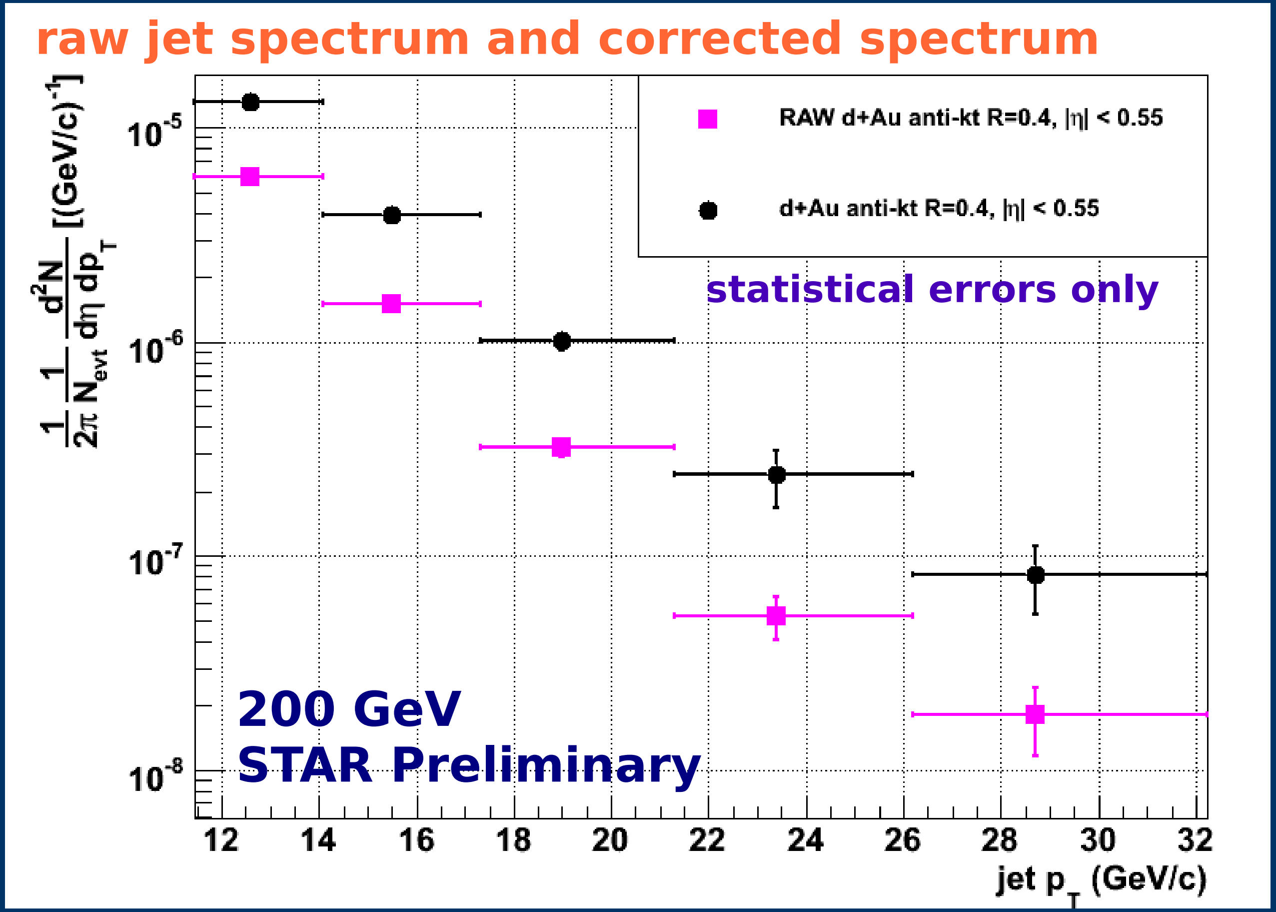
- anti-kt algorithm, R = 0.4
- $p_{T,track/tower} > 0.2$ GeV/c
- $|\eta_{jet}| < 0.55$

bin-by-bin correction:

- ratio of jet p_T spectra PyMC/PyBg
- generalized efficiency:
  - efficiency of jet level cuts
  - p_T resolution
- applicable only if real data p_T spectrum and simulation (PyBg) have the same shape



Correction and uncertainties



limitation of bin-by-bin correction method:
p_T reach is constrained by the raw spectrum

leading syst.uncertainty:
Jet Energy Scale (JES)

charged tracks: 10% uncertainty in TPC tracking efficiency (will be less once we have jet embedding)

towers: 5% uncertainty in BEMC calibration

total uncertainty on average 7%

note:
due to steeply falling spectrum, JES uncertainty effect much larger than statistical errors...

Effect of jet algorithm

different jet algorithms: same value of “R” doesn't mean result is the same (as with JES uncertainty, small shift in jet p_T is huge shift in spectrum)

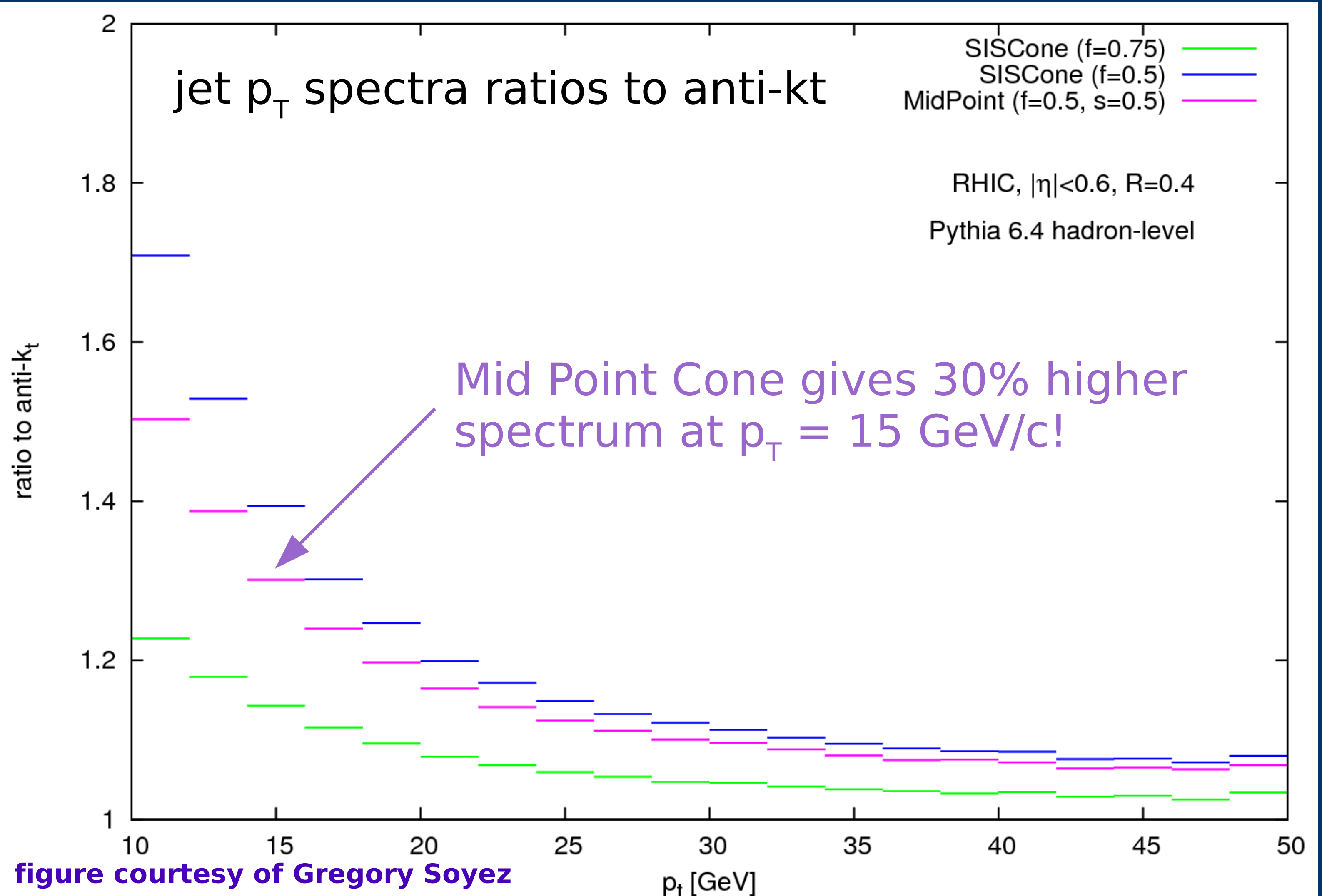
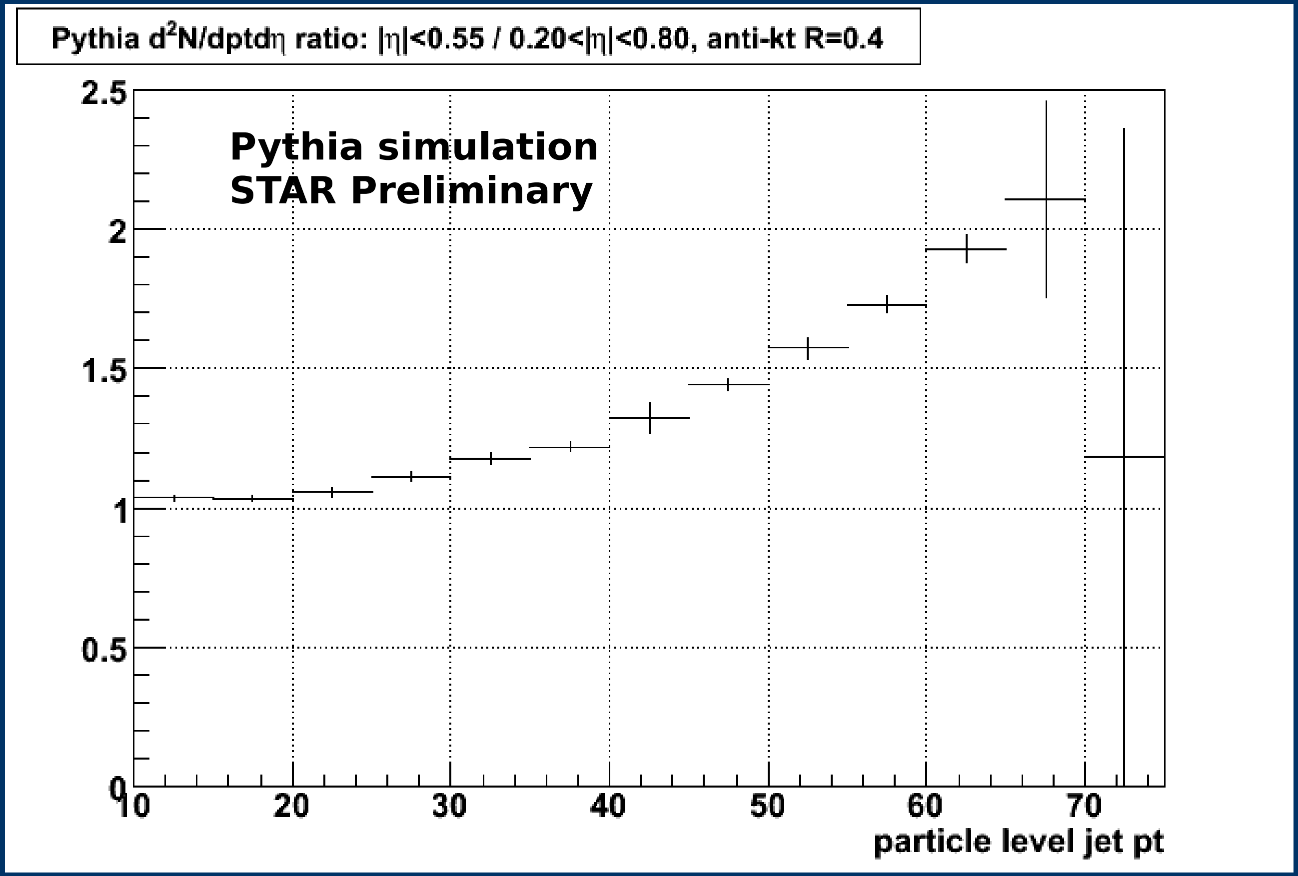


figure courtesy of Gregory Soyez

Pseudorapidity acceptance

jet dN/dη not flat: focusing towards η=0 for high jet p_T

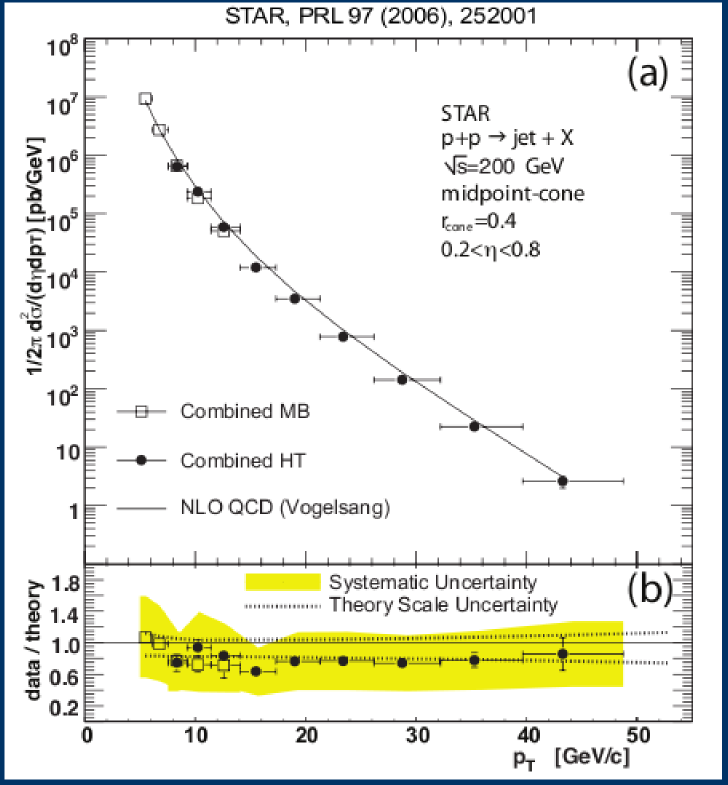
|η|<0.55 vs 0.2<|η|<0.8: 50% effect at 50 GeV/c, negligible below 20 GeV/c:



Jet cross section & relation to p+p

compare to STAR p+p jet cross section:

- Mid Point Cone algorithm
- R = 0.4



number of binary collision scaling:

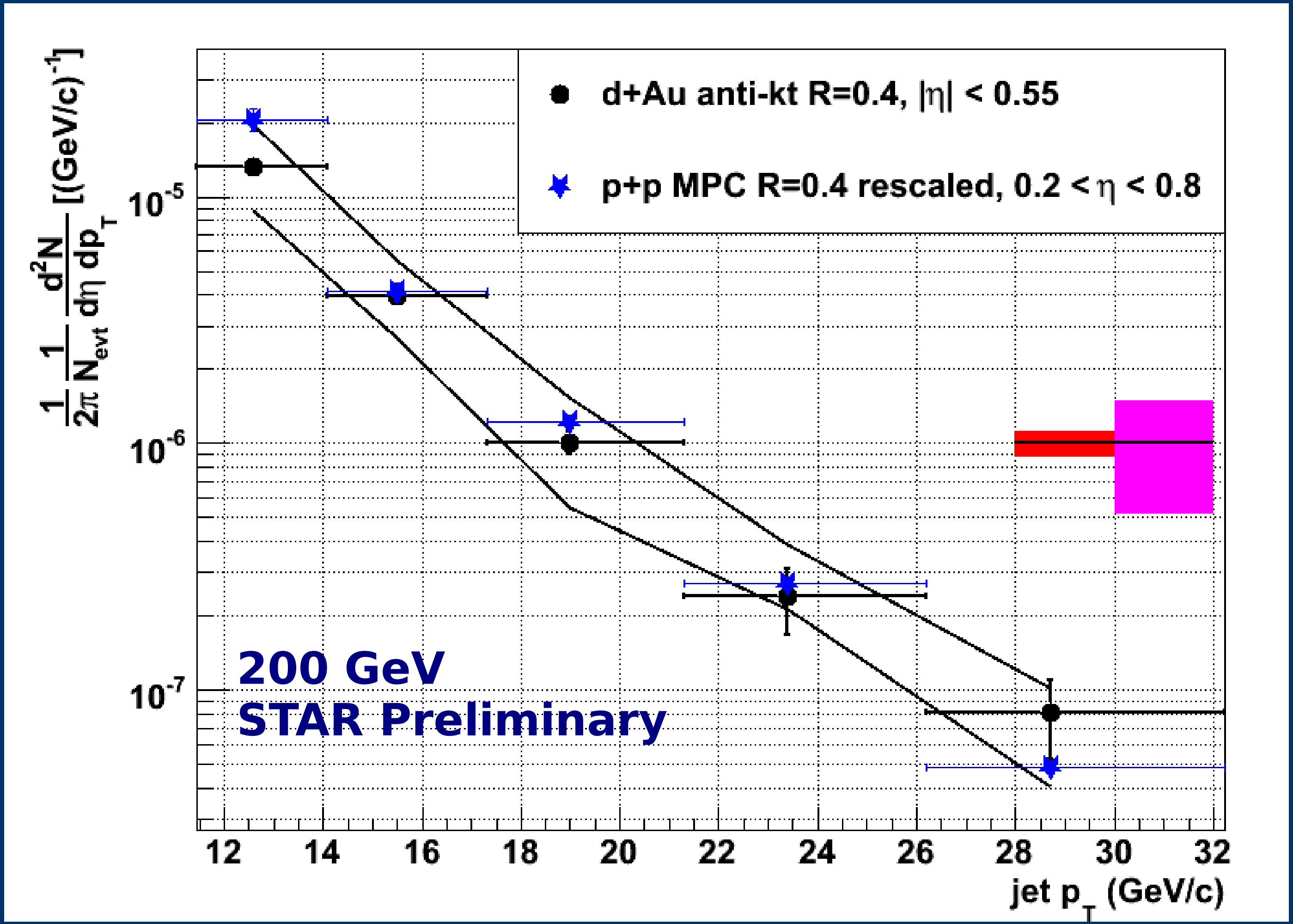
if there are no nuclear effects, hard processes scale according to $\langle N_{bin} \rangle$

for 20% most central run 8 d+Au collisions, $\langle N_{bin} \rangle = 14.6 \pm 1.7$ from MC Glauber

d+Au: jet yield normalised per event rescaling p+p to this level:
$Y_{jet,p+p\ (d+Au\ level)} = \sigma_{jet,p+p} / \sigma_{inel,p+p} * \langle N_{bin} \rangle$

$\sigma_{inel,p+p}$ = 42 mb is p+p inelastic cross section

d+Au jet p_T spectrum, p+p comparison



systematic errors:

black error band:
d+Au JES uncertainty (TPC: 10%, BEMC: 5%)

red box: <N_{bin}> 12% uncertainty

magenta box: p+p total normalization uncertainty (including jet energy scale)

note
- different η range
- different jet algorithm

➔ **d+Au: no significant deviation from N_{bin} scaled p+p**
➔ **further studies of systematics ongoing**

Outlook: towards jet R_{dAu}

need to constrain the systematic uncertainties:

- embedding of jets into realistic detector backgrounds
- further improve understanding of jet energy scale
- use run 8 p+p data as reference: most systematic uncertainties should cancel out
- use the same jet finding algorithm for p+p

use High Tower trigger data:

- extend p_T reach to ~50 GeV/c
- needs luminosity correction (in progress)

Conclusion

Di-jet measurement in 200 GeV d+Au and p+p collisions:

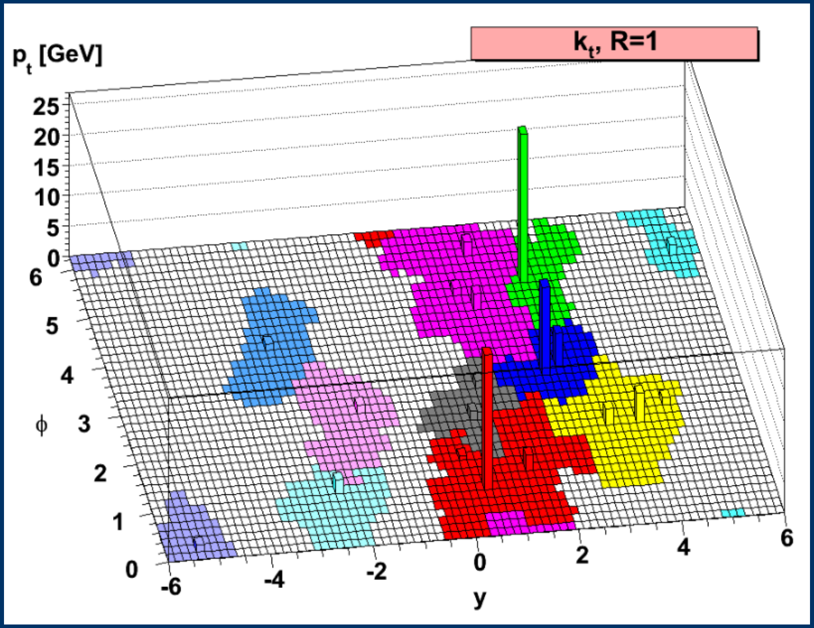
- no strong CNM effects on k_T broadening observed

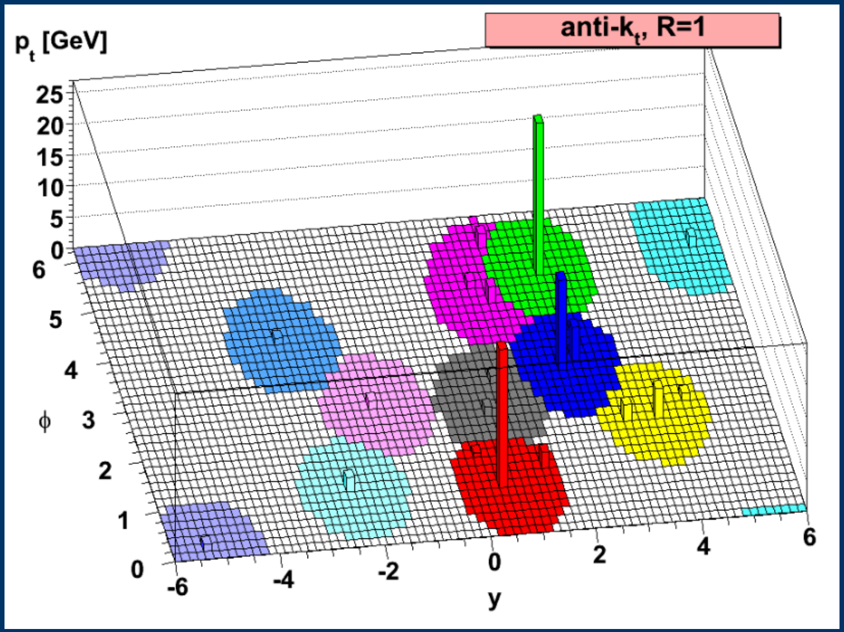
Inclusive jet p_T spectrum in 200 GeV d+Au collisions:

- no significant deviation from N_{bin} scaled p+p
- large systematic uncertainties
- improvements under way:
  - jet embedding
  - run 8 p+p data
- moving towards jet R_{dAu}

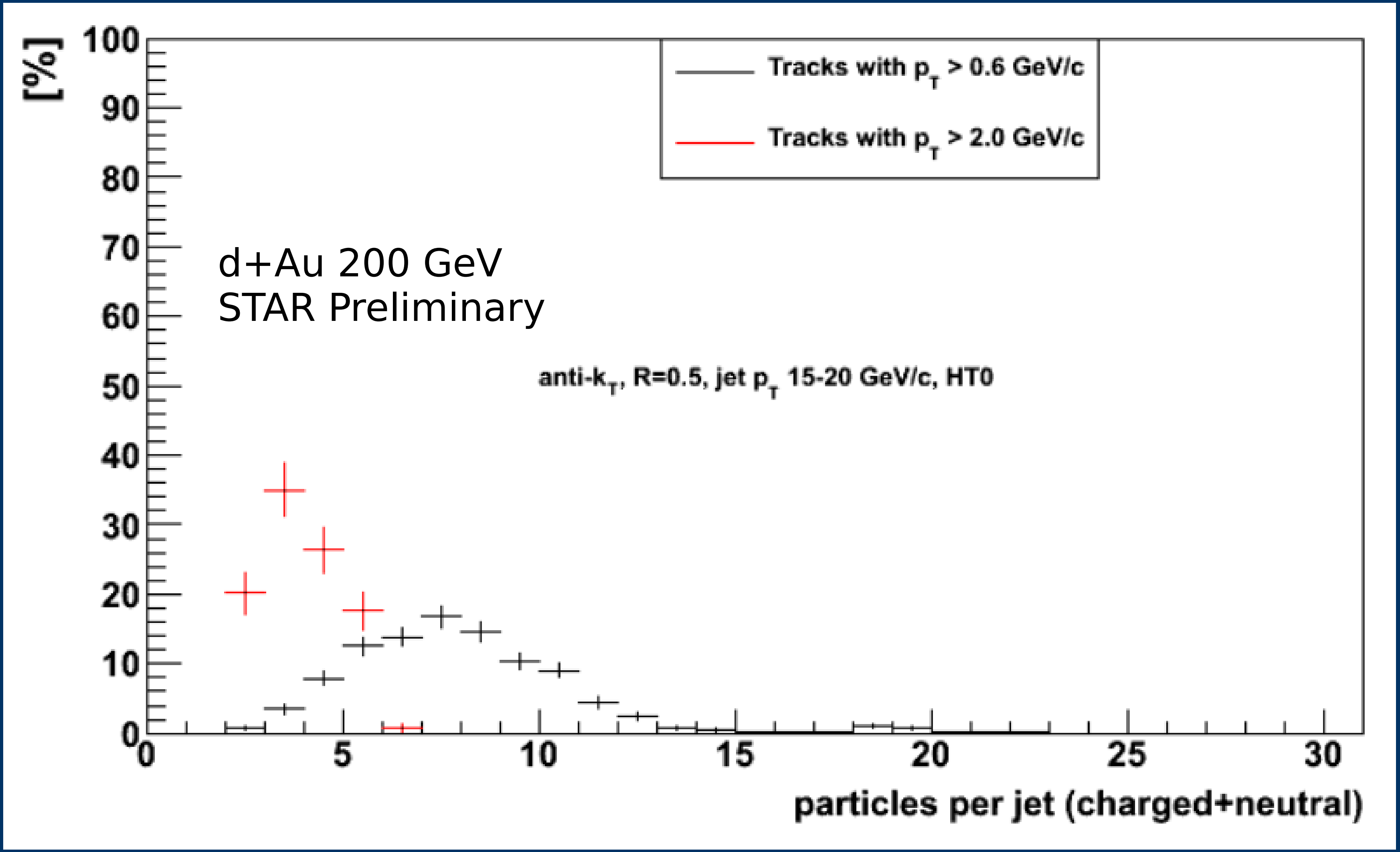
Backup

jet areas/shapes: kt, anti-kt

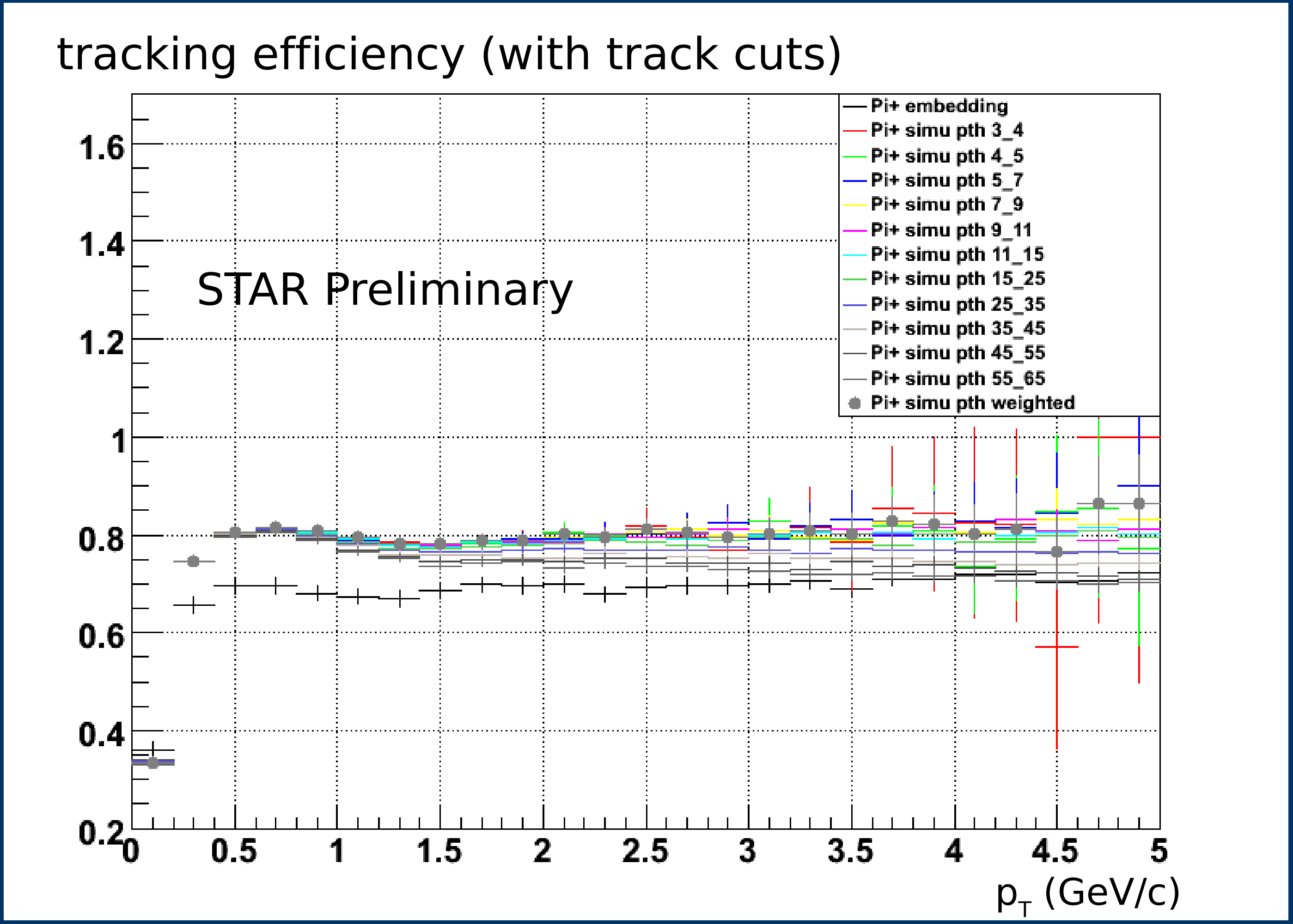




Number of particles per jet



Tracking efficiency: embedding & simulation



Recombination schemes

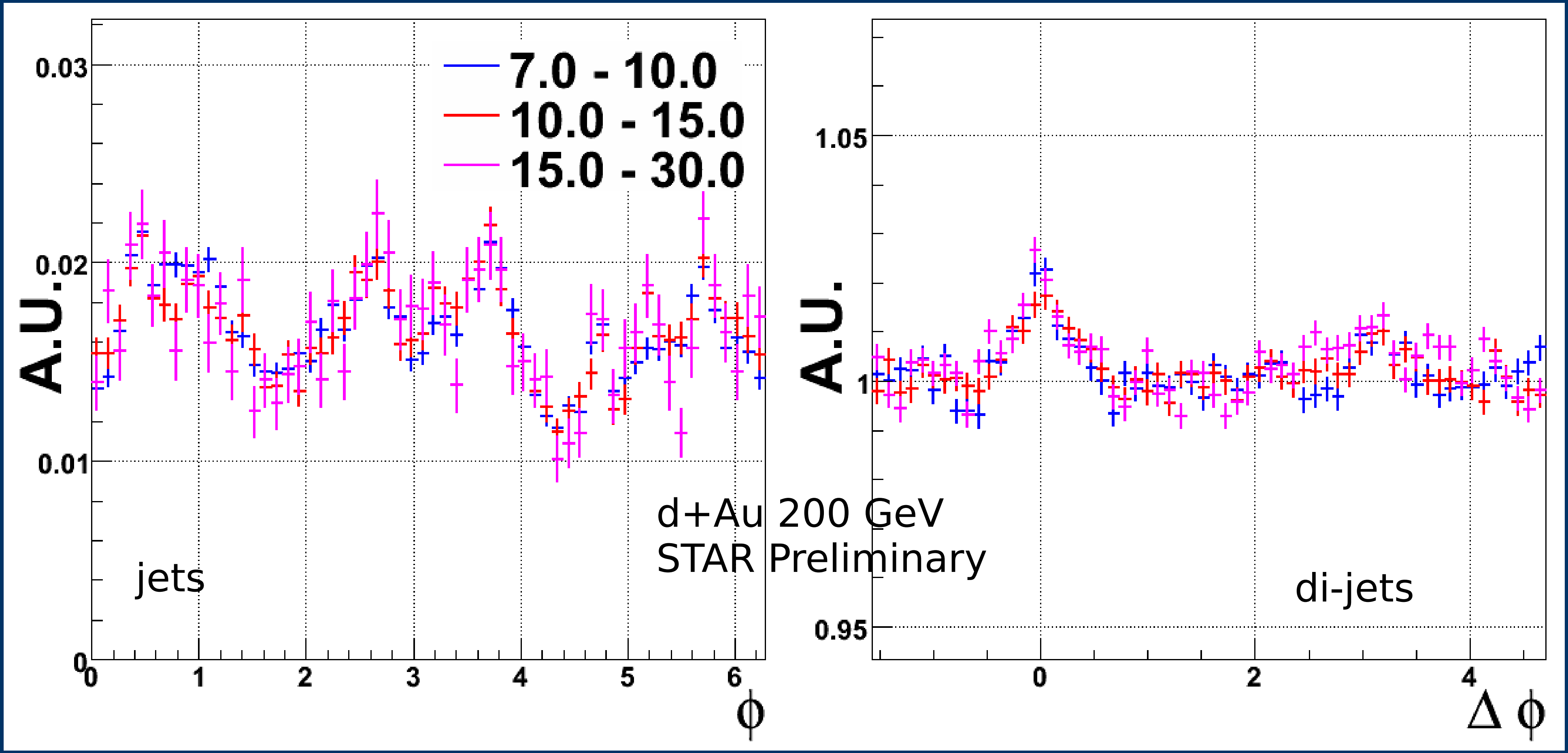
how are 4-momenta of 2 merged object summed?

we are using E scheme (FastJet default):
4-momenta are simply added
choice of mass of measured tracks, towers: zero
jet aquires mass

other possibilities:
p scheme: all objects mass-less & 3-momenta are summed

effect of these expected to be small compared to other systematic effects,
currently under study at STAR

Phi and ΔPhi acceptance



big effect on single jets, small effect on di-jets...

Modified nuclear PDF

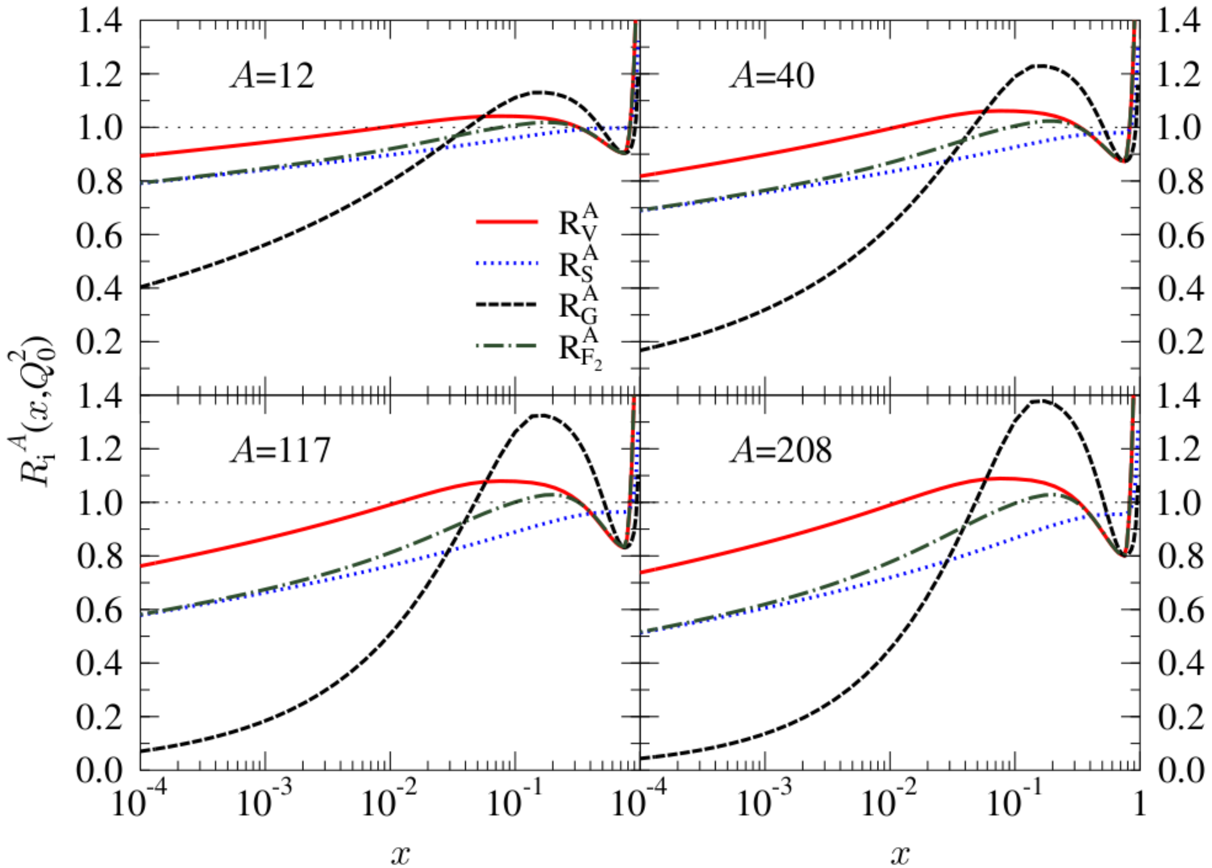
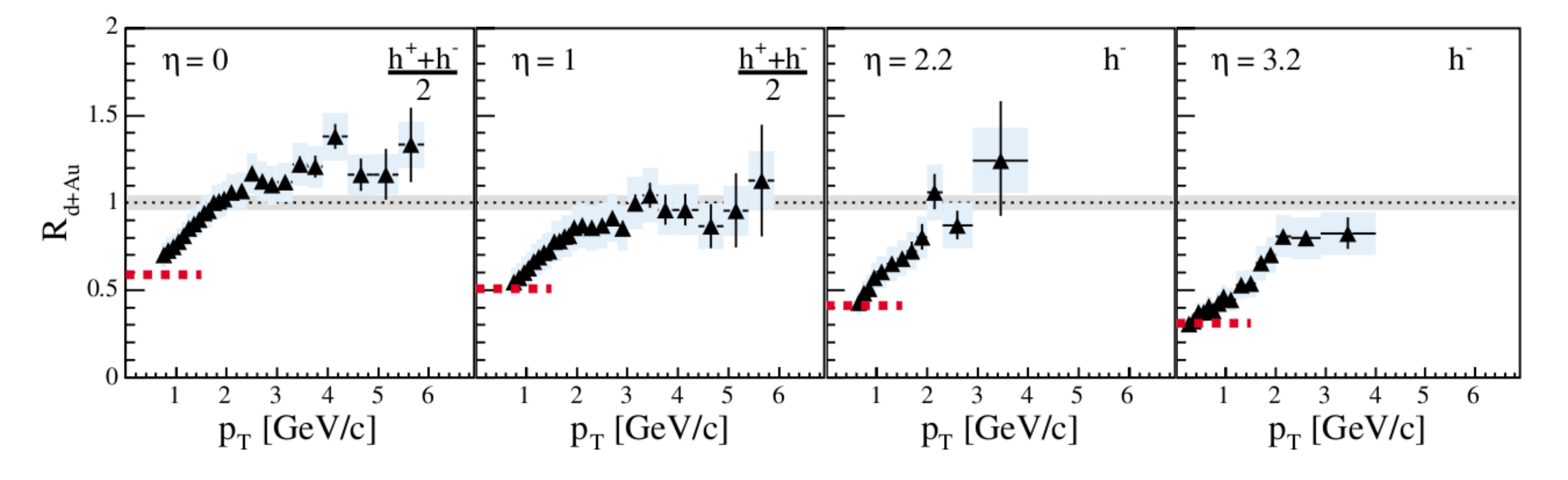


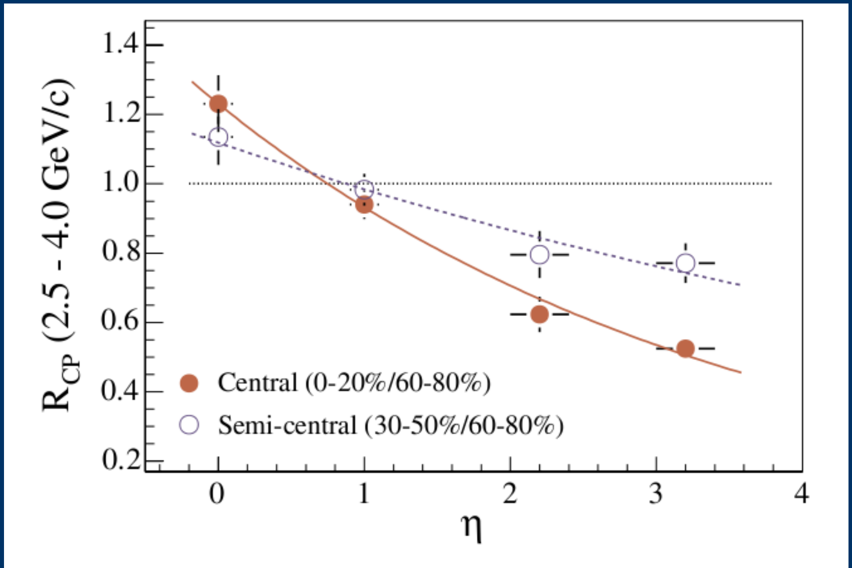
Figure 2: The nuclear modification factors R_V^A, R_S^A and R_G^A for C, Ca, Sn, and Pb at $Q_0^2 = 1.69\,\text{GeV}^2$. The DIS ratio $R_{F_2}^A$ is shown for comparison.

K. J. Eskola, H. Paukkunen, C. A. Salgado, JHEP 0807:102,2008

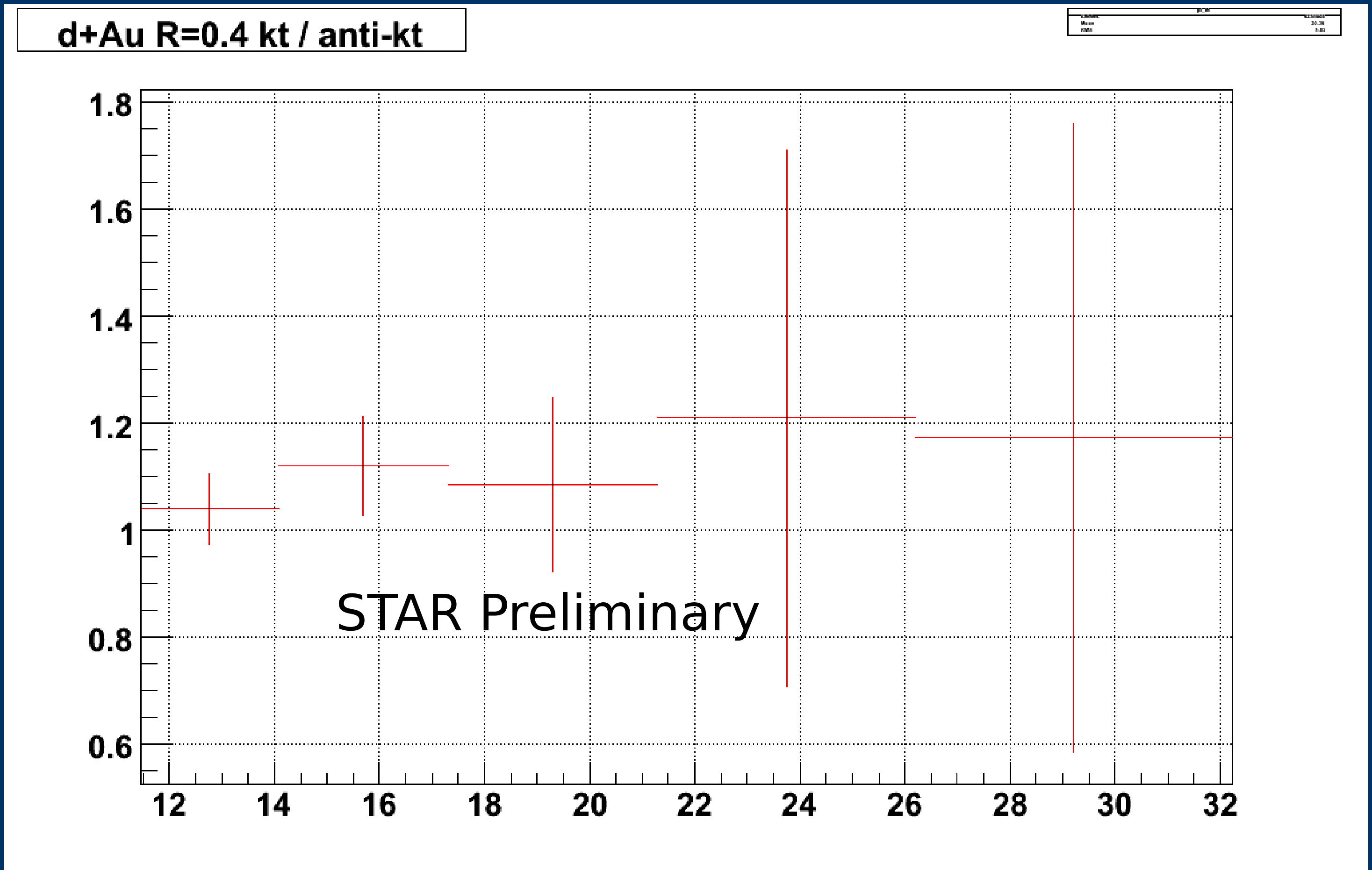
Single particle spectra

from BRAHMS Collaboration, Phys.Rev.Lett.93 242303 (2004)





anti-kt comparison to kt



kt ~10% higher, consistent with kt jets having slightly bigger area!

year 8 luminosities, raw HT spectra

note: no event (VertexZ), d+Au centrality cuts

d+Au, HT trigger (bht2): 8 nb^-1 (p+p equvalent 3.2 pb^-1)

p+p, HT trigger (bht2): 2.7 pb^-1